Long-run growth patterns within Asian NIEs: Empirical analysis based on the panel unit root test, allowing the heterogeneity of time trend and endogenous multiple structural breaks

Matsuki, Takashi and Usami, Ryoichi

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Long-run growth patterns within Asian NIEs: Empirical analysis based on the panel unit root test, allowing the heterogeneity of time trend and endogenous multiple structural breaks

Takashi Matsuki* and Ryoichi Usami

Department of Economics, Osaka Gakuin University,

2-36-1 Kishibeminami, Suita- City, Osaka, 564-8511, Japan

ABSTRACT

This study examines whether or not the convergence of per capita output—which is categorized as catching-up and long-run convergence, defined by Oxley and Greasley (1995)—exists within Asian newly industrializing economies (Asian NIEs), namely, Hong Kong, Singapore, South Korea, and Taiwan. The newly developed panel unit root test, which can allow for multiple structural breaks at various unknown break dates for each time series, is applied to the panels for 1960–2004, which includes the period of the Asian financial crisis. Moreover, in order to confirm the coexistence of the different growth patterns within the Asian NIEs, the heterogeneity—in terms of the inclusion or exclusion of a linear time trend and the types of breaks (in level or slope)—is allowed for each series in the test. The empirical results show that Hong Kong and Singapore have long-run convergence, whereas Korea and Taiwan are yet to converge with Hong Kong.

* Corresponding author. E-mail: matsuki@ogu.ac.jp

I. INTRODUCTION

Hong Kong, Singapore, South Korea, and Taiwan are referred to as the newly industrializing or industrialized economies in Asia (Asian NIEs).[1] The Asian financial crisis damaged each of the four economies to different extents. Korea was the most severely depressed in terms of economic growth (e.g. Asian Development Bank, 1998, 1999). Thus, we need to examine whether the shocks of the financial crisis were severe enough to change the growth strategies of the Asian NIEs or whether they continued to adopt the same strategies even after the crisis. The concept of convergence of per capita output would help us in answering this question.

Lots of empirical studies on convergence have appeared since the work of Barro (1991). Some of the earlier ones are Bernard and Durlauf (1995), Oxley and Greasley (1995), Evans and Karras (1996), Lee, Pesaran, and Smith (1997), and Evans (1998). In recent times, Lim and McAleer (2004) and Kim (2001) have conducted research along these lines, focusing on the economies in Asia.[2] Lim and McAleer (2004) applied some non-stationary time series methods to per capita real GDPs from 1960 to 1992 for the ASEAN-5 countries, namely, Indonesia, Malaysia, the Philippines, Thailand, and Singapore. Overall, they found no evidence of income convergence. Kim (2001) used the panel-based t-ratio and F-ratio tests that relied on the formulation by Evans and Karras (1996) for 17 Asian countries and regions including the Asian NIEs for the period 1960–1992, and presented evidence for conditional convergence among them.

The present paper investigates the long-run growth patterns of the Asian NIEs, which may have changed after the crisis.[3] Thus, this paper applies the panel unit root test with breaks developed by Matsuki and Usami (2008). It allows for flexible specifications in terms of the presence or absence of a linear time trend and the types of structural breaks (in level or slope) for each series. In the next section, the data generating process and the regression model are first introduced; then, the convergence of per capita real output is defined, and the test procedure is explained. The empirical results are discussed in Section 3, and the conclusion is provided in Section 4.

II. ECONOMETRIC METHODOLOGY

II-1. MODEL

There are *M* economies numbered 1, 2, …, *M*, as an index, and each of these possesses the time series data of size *T*. Denote the logarithm of the output or the per capita income of economy *m* and economy *j* (*m* < *j*) at period *t* as y_{mt} and y_{jt} respectively. Then, arranging the difference between y_{mt} and y_{jt}, $y_{mt} - y_{jt}$ ($m = 1, \ldots, M-1, j = m+1, \ldots, M$) in lexicographic increasing order, denote it as $\tilde{y}_{it}$ $(= y_{mt} - y_{jt})$. This study assumes that the series $\tilde{y}_{it}$ is generated by the following data generating process (DGP).

Under Null: $$\tilde{y}_{it} = \alpha_i + \tilde{y}_{it-1} + \varepsilon_{it} \quad (1)$$

Under Alternative: $$\tilde{y}_{it} = \alpha_i^{'} + \beta_i t + \rho_i \tilde{y}_{it-1} + \sum_{h=1}^{2} \delta_{hi} D_{hit} + \varepsilon_{it}, \quad |\rho_i| < 1 \quad (2)$$

$$i = 1, \ldots, N, \quad t = 1, \ldots, T$$

where $N \equiv M(M-1)/2$, and ε_{it} is independently and identically distributed across i and t with a zero mean and a finite variance. Under the stationarity alternative hypothesis (2), the DGP has up to two time shifts in the level or slope in the trend function. δ_{hi} denotes the size of the hth break ($h = 1, 2$); D_{hit}, the dummy variable that represents the hth break; $D_{hit} = DU_{hit}$, the shift in the level; and $D_{hit} = DT_{hit}$, the shift in the slope. $DU_{hit} = 1$ for $t > \tau_{hi}T$ or zero otherwise, and $DT_{hit} = t - \tau_{hi}T$ for $t > \tau_{hi}T$ or zero otherwise, where τ_{hi} denotes the fraction of the hth break defined as $\tau_{hi} = TB_{hi}/T$ ($h = 1, 2$) for all T, in which $0 < \tau_{1i} < \tau_{2i} < 1$, where TB_{hi} denotes the date of the hth break.

The regression model nests the DGPs (1) and (2) as follows:

$$\Delta\tilde{y}_{it} = \hat{\alpha}_i + \hat{\beta}_i t + \hat{\phi}_i \tilde{y}_{it-1} + \sum_{h=1}^{2} \hat{\delta}_{hi} D_{hit} + \sum_{l=1}^{\bar{l}_i} \hat{a}_{il} \Delta\tilde{y}_{it-l} + error \tag{3}$$

where $\Delta\tilde{y}_{it} = \tilde{y}_{it} - \tilde{y}_{it-1}$, $\hat{\phi}_i = \hat{\rho}_i - 1$. $\bar{l}_i$ denotes a lag order parameter and is specified by following the 'general-to-specific' procedure suggested in Ng and Perron (1995).[4]

Let t_i denote the *t*-statistic for the parameter $\hat{\phi}_i$ in Equation (3) for the null hypothesis $\phi_i = 0$ and $\delta_{1i} = \delta_{2i} = 0$ against the alternative hypothesis $\phi_i \neq 0$ and $\delta_{1i} \neq 0$, $\delta_{2i} \neq 0$ for each i. The break dates $\{TB_{1i}, TB_{2i}\}$ are endogenously determined to exist where the one-sided t_i-statistic is minimized in sequential estimations over all possible break dates within the range $0 < \tau_{1i} < \tau_{2i} < 1$, as employed in Zivot and Andrews (1992) and Lumsdaine and Papell (1997). Since $T \to \infty$ for fixed i, the limiting distributions of the minimum t_i-test for the cases of one-time and two-time breaks are provided by Zivot and Andrews (1992) and Lumsdaine and Papell (1997) respectively.

II-2. DEFINITION OF CONVERGENCE

This paper adopts the definition of convergence proposed by Oxley and Greasley (1995) and Lim and McAleer (2004). Catching-up implies that $\tilde{y}_{it}$ is trend-stationary, i.e.

$|\rho_i| < 1$ and $\beta_i \neq 0$ in Equation (2). This category suggests that the difference in the logarithm of per capita output between the two economies is narrowing over time; in other words, the relatively less developed economy is heading towards convergence.[5] Long-run convergence implies that $\tilde{y}_{it}$ is level-stationary, i.e. $|\rho_i| < 1$ and $\beta_i = 0$ in Equation (2). This implies that the two economies have already converged in terms of growth rate and are possibly on the steady-state path. On the other hand, if $\tilde{y}_{it}$ has a random walk component, i.e. $\rho_i = 1$ in Equation (2), the difference in the logarithm of per capita output between the two economies will diverge over time.

II-3. TEST PROCEDURE

Matsuki and Usami (2008) proposed the panel-based unit root test that permits multiple shifts in the level of the trend function at various unknown dates for each cross-sectional unit. It is the extended version of the test based on Fisher's (1932) sum of log *p*-values approach, such as the test proposed by Maddala and Wu (1999) (hereafter, the MW test).[6] It is defined as follows:

$$Fisher\_B = -2\sum_{i=1}^{N} \log p_i \tag{4}$$

where p_i denotes a *p*-value associated with the minimum t_i-test. As shown in Fisher (1932), when there are *N* continuous tests, and they are independent, the *p*-value corresponding to each of the tests has an independent and uniform (0, 1) distribution; then, the statistic of $-2\sum_{i=1}^{N} \log p_i$ has a chi-square distribution with 2*N* degrees of freedom. Based on this fact, the Fisher_B test also has a chi-square distribution with 2*N* degrees of freedom.

In order to calculate p_i that constitutes the Fisher_B statistic, the empirical distribution of the minimum t_i-test needs to be calculated using Monte Carlo simulations with the actual sample size; this is because the minimum t_i-test has a non-standard distribution under the null hypothesis. In the simulation, the following two DGPs are assumed under the null hypothesis:

$$\tilde{y}_{it} = \tilde{y}_{it-1} + \varepsilon_{it} \tag{5}$$

$$\Delta\tilde{y}^*_{it} = \hat{\alpha}_i + \sum_{k=1}^{\bar{k}_i} \hat{\gamma}_{ik_i} \Delta\tilde{y}^*_{it-k} + \varepsilon^*_{it} \tag{6}$$

In Equation (5), $\tilde{y}_{it}$ is generated by a driftless random walk process for each *i*, where ε_{it} denotes an *i.i.d.* $N(0,1)$ error across *i* and *t*. In Equation (6), ε^*_{it} is obtained by the residual bootstrap method with the SUR residuals of Equation (6), which retains the cross-sectional dependency structure in panels; then, $\Delta\tilde{y}^*_{it}$ is generated by Equation (6) with the series of ε^*_{it} and the estimated parameters $\hat{\gamma}_{ik_i}$ and $\hat{\alpha}_i$ in the SUR estimation, where $\hat{\alpha}_i$ is set at 0 when a time trend is not contained in Equation (3) (for additional details, see Wu and Wu, 2001).[7]

III. EMPIRICAL ANALYSIS

The data are obtained from the Penn World Table (PWT) 6.2.[8] The series of real GDP per capita adjusted for terms of trade changes (RGDPTT) is employed from 1960 to 2004, since economic relations with foreign countries have played a vital role for the Asian NIEs; similar to the case for the ASEAN-5 countries analysed in Lim and McAleer (2004). All the series used in this study are taken in natural logarithms.

The results are provided in Table 1. The fourth and fifth columns present the

Fisher_B test in the case of one-time and two-time breaks in level. Two out of eight tests show significant rejections at the 10% significance level. However, this represents rather weak evidence of convergence; therefore, it is insufficient to confirm the growth patterns of the Asian NIEs.

The evidence is weak possibly due to the homogeneity assumption on the presence of a time trend and the types of structural breaks in Equation (3) for all *i*. Therefore, for each *i*, the series $\tilde{y}_{it}$ is regressed in the following three different specifications of Equation (3): (1) without a time trend but with level shifts, (2) with a time trend and level shifts, and (3) with a time trend and slope shifts. Each of these specifications expresses a unique growth pattern.

In Equation (3), we consider 10 cases. These are listed in Table 2. The results of the Fisher_B test in those cases are presented in Table 3. The results obtained under Equation (6) are mainly discussed below. The Fisher_B test can significantly reject the null hypothesis in nine cases under the assumption of one break and in three cases under the assumption of two breaks. Taking into consideration these significant results does not reveal the apparent difference in the growth patterns across the economies; therefore, consistent implications can be obtained from the most reliable results among them in terms of the rejections at the lowest significant level, which are CASE 8 and CASE 10 under the one-break assumption. The common growth strategies examined in both cases imply that the pair-wise growth experiences of Hong Kong–Korea and Hong Kong–Taiwan represent a catching-up process; those of Hong Kong–Singapore and Korea–Taiwan represent long-run convergence. In other words, Hong Kong and Singapore have a stable ratio of per capita outputs over the long term. Maintaining the state of long-run convergence between them, both Korea and Taiwan have been chasing Hong Kong by narrowing the relative gaps in their per capita real outputs over the sample period. With regard to the relationships between Hong Kong–Korea and Hong Kong–Taiwan, if the estimates of the coefficients obtained from individual regression (shown in Appendix (Table 2A)) are evaluated with respect to their signs and values, the existence of the catching-up phenomenon is also supported for these pairs of economies.[9] With regard to the case of a one-time slope shift, each of the difference series, calculated by subtracting Korea or Taiwan's logarithm of per capita real output from that of Hong Kong, has the positive estimate of a constant (α) and the negative estimate of the slope of a time trend (β). The signs of these estimates imply that there exists the initial gap of outputs between the two economies; however, this gap has been decreasing at a constant speed over time. In other words, the gap suggests the existence of the catching-up phenomenon. In addition, in the difference series for each pair of economies, the estimate of δ—which is the coefficient of the dummy variable for the slope shift—is also negative and its absolute value is much larger than that of β. This suggests that the speed of catching-up was dramatically accelerated at a break date. In other words, Korea and Taiwan have been catching-up with Hong Kong at a speed that was accelerated after 1985 and 1990 respectively.

The fact that both CASE 8 and CASE 10 also imply long-run convergence between Korea and Singapore is inconsistent with the findings described above. Moreover, the categorization of the bilateral relations between Singapore and Taiwan is different in these cases. The discussion under Equation (6) is also supported in the case of Equation (5). Apart from CASE 8 and CASE 10, CASE 7 is significant at the lowest significance level for the one-break model under this DGP. This additional case suggests the existence of a catching-up process between Korea and Singapore; however, this is not conclusive.[10]

IV. CONCLUSION

This paper has examined the convergence hypothesis of per capita real output in the Asian NIEs by applying the panel-based unit root test permitting multiple shifts in level or slope at various unknown dates for each time series. Since the test also allows for flexible specifications in terms of the presence or absence of a linear time trend and the types of breaks (shifts in level or slope) for each series, different growth patterns across economies have been investigated simultaneously.

The empirical analysis revealed the following facts: Although the long-run growth paths of the Asian NIEs were shifted due to one or two external shocks, Hong Kong and Singapore have been on the path of long-run convergence, while Korea and Taiwan have been catching-up with Hong Kong, maintaining their bilateral relations, characterized by long-run convergence. For the pairs of Korea–Singapore and Singapore–Taiwan, however, consistent evidence could not be found.

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FOOTNOTES

1. Krugman (1994), Young (1995), Kim and Lau (1996), and others discussed the sources of their rapid economic growth from the 1980s to the mid 1990s.
2. For income convergence among countries, Li and Papell (1999) examined the existence of convergence among 16 OECD countries by applying the univariate unit root test with one endogenous trend break; using the panel unit root tests and panel cointegration tests, McCoskey (2002) investigated whether a convergence club is formed in sub-Saharan African countries.
3. Hooi and Smyth (2007) used the univariate and panel versions of Lagrange multiplier (LM) unit root test that can treat two structural breaks in investigating the validity of the purchasing power parity hypothesis in 15 Asian countries.
4. Beginning with $\bar{l}_i = 8$, the value of $\bar{l}_i$ is reduced one by one until $\hat{a}_{i\bar{l}}$ is estimated to be different from zero at the 10% significance level.
5. Catching-up is intuitively comprehensible if the signs of $\hat{\alpha}_i$ and $\hat{\beta}_i$ are opposing, $\hat{\alpha}_i > 0$ and $\hat{\beta}_i < 0$ or $\hat{\alpha}_i < 0$ and $\hat{\beta}_i > 0$, although a particular account has not been provided in Oxley and Greasley (1995) and Lim and McAleer (2004).
6. The MW test is built by applying Fisher's p-value combination method to N augmented Dickey-Fuller t-tests; therefore, it does not allow for breaks.
7. When error terms are correlated in DGP across a cross-sectional unit i, the Fisher_B test does not have a chi-square distribution under the null because the minimum t_i-tests are also correlated across i. Thus, without any correction, the test might possess biases towards over- or under-rejections of the null. In order to correct these biases, by using the bootstrap sample $\tilde{y}_{it}^*$ ($t = 1, \ldots, T$) obtained by Wu and Wu's

(2001) resampling scheme, the empirical distribution function of the Fisher_B test is generated through simulation. The simulation provides the appropriate small-sample critical values for the test; these will be shown in Table 1A. Based on these critical values, the test is conducted in an appropriate manner.

8. Formally, Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.2, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, September 2006.
9. The estimation results for each series in the case of two-time breaks are available on request.
10. Under Equation (6), if CASE 6 and CASE 7, which are significant at the 5% significance level in the case of one-break model, are added to facilitate the interpretation, the relation between Korea and Singapore may also be traced to the catching-up process.

Table 1. The results for the Maddala and Wu (1999) test and the Fisher_B test in the case of shifts in level

DGP Model	Regression Model	MW test (No Break)	Fisher_B test	
			One Break	Two Breaks
(5)	constant & trend	16.477	16.357	20.407 *
	constant	16.893	17.969	15.208
(6) [a]	constant & trend	17.062	14.736	15.209
	constant	19.060	21.225 *	18.231

* denotes statistical significance at the 10% level.

[a]In the case of cross-sectionally dependent errors in the DGP, the critical values of the MW test and the Fisher_B test are tabulated in Table 1A in Appendix.

Table 2. The cases of the series and the regression models

	Series [a]	Regression Model [b]	
		Time Trend	Type of Break
CASE 1	HKG-KOR, HKG-TWN, KOR-SGP, SGP-TWN	with	level shift
	HKG-SGP, KOR-TWN	without	level shift
CASE 2	HKG-KOR, HKG-TWN, KOR-SGP	with	level shift
	HKG-SGP, KOR-TWN, SGP-TWN	without	level shift
CASE 3	HKG-KOR, HKG-TWN, SGP-TWN	with	level shift
	HKG-SGP, KOR-SGP, KOR-TWN	without	level shift
CASE 4	HKG-KOR, KOR-SGP	with	level shift
	HKG-SGP, HKG-TWN, KOR-TWN, SGP-TWN	without	level shift
CASE 5	HKG-KOR, HKG-TWN	with	level shift
	HKG-SGP, KOR-SGP, KOR-TWN, SGP-TWN	without	level shift
CASE 6	HKG-KOR, HKG-TWN, KOR-SGP, SGP-TWN	with	slope shift
	HKG-SGP, KOR-TWN	without	level shift
CASE 7	HKG-KOR, HKG-TWN, KOR-SGP	with	slope shift
	HKG-SGP, KOR-TWN, SGP-TWN	without	level shift
CASE 8	HKG-KOR, HKG-TWN, SGP-TWN	with	slope shift
	HKG-SGP, KOR-SGP, KOR-TWN	without	level shift
CASE 9	HKG-KOR, KOR-SGP	with	slope shift
	HKG-SGP, HKG-TWN, KOR-TWN, SGP-TWN	without	level shift
CASE 10	HKG-KOR, HKG-TWN	with	slope shift
	HKG-SGP, KOR-SGP, KOR-TWN, SGP-TWN	without	level shift

[a]HKG, KOR, TWN, and SGP denote Hong Kong, Korea, Taiwan, and Singapore, respectively.

[b]There are three different specifications of a regression model: (1) without a time trend but with level shifts, (2) with a time trend and level shifts, and (3) with a time trend and slope shifts. The first specification implies long-run convergence where the magnitude of the gap of (log) per capita output between two economies changes one or two times, but it's mean-reverting property holds during each of the periods before and after the changes. The second one implies catching-up process at a constant speed where the magnitude of the gap also changes one or two times, but it continues to diminish even after the changes. The third one implies catching-up process where its speed changes one or two times.

Table 3. The results for the Maddala and Wu (1999) test and the Fisher_B test in the ten cases

DGP Model	CASE [a]	MW test (No Break)		Fisher_B test One Break		Fisher_B test Two Breaks	
(5)	1	23.539	**	19.394	*	23.836	**
	2	19.964	*	20.362	*	23.707	**
	3	20.060	*	20.060	*	24.733	**
	4	18.773	*	19.550	*	15.971	
	5	17.957		21.028	*	24.604	**
	6	-		23.859	**	16.479	
	7	-		27.084	***	17.395	
	8	-		27.168	***	16.945	
	9	-		20.166	*	14.450	
	10	-		30.393	***	17.860	
(6) [b]	1	24.367	**	18.390		18.987	
	2	21.132	*	19.797	*	19.171	*
	3	22.697	**	19.675	*	20.733	*
	4	20.435	*	19.614	*	14.226	
	5	19.746	*	21.479	*	20.825	*
	6	-		22.074	**	15.194	
	7	-		26.055	**	16.680	
	8	-		26.406	***	15.649	
	9	-		20.283	*	14.365	
	10	-		30.122	***	17.163	

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

[a]See the cases of the series and the regression models in Table 2.

[b]In the case of cross-sectionally dependent errors in the DGP, the critical values of the MW test and the Fisher_B test are tabulated in Table 1A in Appendix.

Table 1A. The critical values of the Maddala and Wu (1999) test and the Fisher_B test in the case of cross-sectionally dependent errors

Test	Regression Model	10%	5%	1%
MW test	constant & trend	19.243	22.084	28.375
	constant	19.574	22.687	28.454
	CASE 1	19.091	22.014	27.598
	CASE 2	18.685	21.377	26.614
	CASE 3	18.675	21.140	27.002
	CASE 4	18.638	21.365	26.687
	CASE 5	18.909	21.449	27.192
Fisher_B test				
One Break	constant & trend	19.155	22.004	27.891
	constant	19.309	21.820	27.802
	CASE 1	18.968	21.706	27.935
	CASE 2	18.908	21.443	26.925
	CASE 3	18.885	21.300	26.374
	CASE 4	18.911	21.644	26.904
	CASE 5	19.018	21.674	26.882
	CASE 6	18.921	21.571	27.192
	CASE 7	18.923	21.373	26.301
	CASE 8	18.607	20.831	26.015
	CASE 9	18.534	21.196	27.372
	CASE 10	18.638	21.555	26.236
Two Breaks	constant & trend	19.624	22.588	27.935
	constant	19.177	21.824	28.162
	CASE 1	19.286	22.032	27.954
	CASE 2	19.128	21.702	27.082
	CASE 3	19.018	21.506	26.479
	CASE 4	19.068	21.548	27.375
	CASE 5	19.068	21.553	27.559
	CASE 6	18.896	21.665	27.407
	CASE 7	18.742	21.208	25.846
	CASE 8	18.690	21.333	27.237
	CASE 9	18.664	21.134	26.902
	CASE 10	19.026	21.587	26.911

Table 2A. The estimation results for each series in the case of a one-time break

Type of Break	Series	α	β	φ	δ	*Min t*	l	Break Date
Level	HKG - KOR	0.236		-0.248	-0.107	-3.429	1	1993
	HKG - SGP [7, 8, 10]	0.032		-0.268	-0.036	-4.293	1	1994
	HKG - TWN	0.145		-0.195	-0.085	-2.564	0	1994
	KOR - SGP [8, 10]	-0.352		-0.384	0.139	-4.349	4	1984
	KOR - TWN [7, 8, 10]	-0.092		-0.441	0.031	-4.474	1	1989
	SGP - TWN [7, 10]	0.253		-0.355	-0.100	-4.602	1	1983
	HKG - KOR	0.662	-0.016	-0.555	0.158	-4.919	6	1979
	HKG - SGP	0.014	0.001	-0.334	-0.070	-4.288	1	1994
	HKG - TWN	0.270	-0.002	-0.314	-0.077	-3.932	0	1994
	KOR - SGP	-0.469	0.002	-0.484	0.118	-4.763	1	1984
	KOR - TWN	-0.090	-0.001	-0.509	0.061	-4.680	1	1987
	SGP - TWN	0.429	-0.003	-0.546	-0.085	-4.937	1	1984
Slope	HKG - KOR [7, 8, 10]	0.943	-0.001	-0.939	-0.024	-5.723	4	1985
	HKG - SGP	0.014	0.001	-0.318	-0.008	-4.058	1	1993
	HKG - TWN [7, 8, 10]	0.784	-0.004	-0.942	-0.021	-5.795	4	1990
	KOR - SGP [7]	-0.355	-0.0003	-0.383	0.007	-3.348	1	1974
	KOR - TWN	-0.079	-0.001	-0.438	0.003	-3.858	1	1983
	SGP - TWN [8]	0.501	-0.072	-0.450	0.067	-3.994	1	1963

7, 8, and 10 denote the series used in CASE 7, CASE 8, and CASE 10, respectively.